EXPERIMENTAL STUDIES OF STRENGTH AND DURABILITY ANALYSIS OF CONCRETE INCORPORATING ULTRAFINE SLAG

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ABSTRACT

There have been enormous researches going on the use and utilization of industrial, agricultural and thermoelectric plant residues in the production of concrete. Production of high performance concrete (HPC) plays an important role with different pozzolanic materials like fly ash, condensed silica fume, blast furnace slag, rise husk ash etc. There has been increase in the consumption of mineral admixture by cement and concrete industries. This rate is expected to increase day by day. The presence of mineral admixture in concrete is known to impart significant improvement in workability and durability in concrete. The present study involves the use of mineral admixture 'ultrafine slag" as a cementitous material for cement and to evaluate the threshold limit of replacement of cement. Main aim of this work is to evaluate the flexural strength of High strength concrete by partial replacement of cement (0, 8, 10, 12, and 14%) with ultra-fine slag (Alccofine 1203) for M60 grade of concrete. OPC of 43grade from single source is used in this investigation. The addition of alccofine shows an early strength gaining properties with increase flexural strength of concrete. In the last millennium concrete had demanding requirements both in technical performance wise and economy wise and yet greatly varied in application from architectural masterpieces to the simplest of utilities. This study presents the results of an experimental investigation carried out to evaluate the flexural strength of concrete incorporated with ultrafine slag (alccofine) by studying the effects of different proportions of ultrafine slag in the mix and to find optimum dose of alccofine content in the mix. The concrete specimens were cured on normal moist curing under elevated atmospheric temperature for better heat of hydration. Main aim was confined to find the change of flexural strength of reinforced concrete beams. The flexural strength was determined at 7 ,14 and 28 days and comparisons were made for both plain concrete and reinforced cement concrete (R.C.C). Further experimental investigations were carried out to find the effect of steel fibers embedded in concrete along with ultra fine slag. Different durability analysis of concrete incorporating ultrafine slag was also carried out. The addition of alccofine shows an early strength gaining property. The combination of ordinary Portland cement (OPC) with alccofine was found to increase the compressive strength of concrete on all ages when compared to concrete made with ordinary Portland cement alone and has showed excellent durability characteristic with hydrochloric acid. Alccofine matches the dimensional realms of silica fume as it is finer than GGBS. Silica fume is hard to get hold of as it is imported from outside of India. Based upon

the results of this research alccofine - 1203 can be proposed as the substitute for silica fume in partial replacement of concrete. Manufacturing of high performance concrete (HPC), which is majorly used as building material in the major and huge infrastructure projects, is a daunting task. Though the recent advancements have conquered the hurdles of the preparation of high performance concrete, the use of green materials such as Fly Ash and Rice Husk Ash is limited. Apart from the green materials, many conventional and mineral admixtures or micro materials are available in the market, which enhances the quality and performance of concrete such as Metakaoline, Alccofine and Silica Fume etc. The quality of concrete mix is assessed through various mechanical properties like compressive strength, flexural strength and split tensile strength and various durability tests like rapid chloride penetration test (RCPT), sorptivity test, chloride resistance test, accelerated corrosion test and sea water attack test are carried out to analyse the performance of HPC. The objective of this study is to evaluate the structural strength of high performance concrete by utilizing green and pozzolanic material as supplementary cementitious material.

Key words: *High performance concrete, alccofine, steel fibers, flexural strength*

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1. INTRODUCTION

1.1 Cement and Concrete

Concrete is a hard material that has cementitious medium within which aggregates are embedded [2,3]. With the development of concrete technology the use of concrete in the construction industries has gained pace. Cement is one of the major constituent of a concrete. Materials other than cement used in the manufacture of concrete are coarse and fine aggregates, admixtures and water. Cement is an extremely important constituent of a concrete as it binds together other materials. Concrete is used extensively in the production of buildings, bridges, harbours, runways, roads, etc. Compressive strength is an important parameter which determines the characteristic of a concrete [3]. For the construction of high rise buildings and long span bridges the use of high strength concrete (compressive strength 60-100 MPa) were commercially started in the late 70's This made the concrete technologist to develop high performance concrete (HPC) which not only give high strength but also perform satisfactorily during its service period.

1.2 Environmental Concerns

Manufacture of cement releases CO_2 in the atmosphere causing severe impact on the environment. Recent reports states that the cement industries produce 5% of global man made CO_2 emissions. The amount of CO_2 emitted by the cement industries is nearly 900kg per 1000kg of cement produce [3]. Considering the predicted increase in production there is pressure on the cement industries to maintain or reduce CO_2 emission. A global reduction upto 8% in green house gas emission was set in the Kyoto Protocol in 1997. As a result a climate change tax was also introduced. Therefore, it is evident that, in order to keep its position as a dominant material in the future, the model of concrete industry needs to be shifted towards "sustainability"

1.3 High Performance Concrete

Definition of concrete has been changed with passage of time and with new researches. It is no longer made of cement, aggregates and water only. It has to incorporate additional ingredients such as admixtures and supplementary cementitious materials (SCMs) such as silica fume, fly ash, Ground granulated blast furnace slag (GGBS), rice husk ash, Ultra fine slag, etc [1,2,3,5]. High performance concrete not only posses high strength but it is

especially designed to meet many functional requirements such as impermeability, resistance to frost, thermal cracking etc. There is reduction in the size of crystalline compounds especially calcium hydroxide while utilizing pozzolonic materials as a result thickness of interfacial transition zone in high strength concrete get reduced. Due to this densification overall strength of concrete gets increased.

1.4 Review of literatures

To define the objectives and scope in the proposed research area, detailed literature survey is carried out in terms of both, experimentation and theory pertaining to the proposed area of research. This chapter discusses the past research conducted by various researchers to study the applications & different methodology used in understanding of tests and finding due to the above said along with behavior of Alccofine 1203 as an admixture to concrete. This chapter gives a comprehensive review of the findings along with directions for future explorations

Deval kulkarni Parekh [7] studied the experimental study on high-performance concrete, with mixing of alccofine and flyash. Aim of this research was to evaluate the performance of high performance concretes (HPC) containing supplementary cementitious materials. They used ternary blend of alccofine 8% and fly ash 16% to find the compressive and flexural strength of concrete. They also suggested that alccofine has better performance compare to other slag materials and microsilica and helpful to make concrete workable.

Saurav Gupta [3] conducted an experimental investigation to determine the strength relationship of concrete cube and concrete cylinder using ultrafine slag. Their results indicated that hardened properties of concrete increases after adding alccofine and optimum dose of alccofine is close to 12%. They conducted experiments on M50 grade of concrete with water cement ratio 0.40

Jamnu Upadhyay [5] investigated the effect of alccofine as a supplementary cementing and filling material. They used a ternary blend of alccofine 10% and fly ash 30% with ordinary Portland cement. They also suggested that alccofine increases the filling and passing ability of concrete and also increases resistance to segregation.

1.5 Research Objectives

The primary objectives of this research work are to estimate the strength and durability analysis of concrete incorporating ultrafine slag. Following sub objectives are defined to achieve above main objective of research.

- To determine the optimum dose of ultrafine slag which can provide maximum gain in strength of concrete cubes and concrete cylinders.
- To find the effect of ultrafine slag on the flexural strength of reinforced concrete beams
- To find the effect of ultrafine slag on steel fiber reinforced concrete.
- Durability analysis of concrete beams incorporating ultrafine slag.

1.6 Scope of Research Work

To accomplish the defined objectives for this research work the following scope of work is defined

- Collecting and identifying the samples of appropriate micro materials suitable for the concrete mix. In this research work ultra fine slag is used as micro materials
- Detailed laboratory investigations for determination of mechanical properties of high performance concrete like compressive strength, flexural strength, split tensile strength test and slump test were performed with different proportions of ultra fine slag.
- Detailed laboratory investigations to determine the gain in flexural strength of reinforced concrete beams using ultrafine slag
- Detailed laboratory investigations to determine the split tensile strength of steel fiber reinforced concrete using ultrafine slag.

2 EXPERIMENTAL INVESTIGATION

2.1 General

The aim of this experimental program is to compare the behavior of ultra fine slag (Alccofine 1203) in use as a supplementary cementing material when subjected to different tests. All the tests carried out on concrete are mentioned here in this chapter followed by a brief description about mix design & aggregates.

2.2 Materials Used

In this chapter different material properties has been discussed. At first most significant properties of structural concrete has been identified and then limits of supplementary cementitious materials is established. Various factors which directly or indirectly effects the properties of concrete is discussed so that the experimental programme can be designed to investigate the comparative influence of supplementary cementituous materials (SCMs) on the properties of concrete

2.2.1 Aggregates

Generally two types of aggregates are used in the preparation of concrete and they are classified on the basis of their size. Coarse aggregates have sizes more than 4.75mm and fine aggregates have size less than 4.75mm [27]. Sieve analysis of coarse and fine aggregates is tabulate in table in Table 2.1 and Table 2.2

Table 2.1 Sieve Analysis of Coarse Aggregate (20mm)

Coarse Aggregate (20mm)					**Specification As per IS-383**					
Total weight in gms= 30000					**Percentage Passing for single size aggregate of Nominal size (mm)**					
IS Sieve	**Weight retained**	**Cumulative weight retained**	**Cumulative % Retained**	**Cumulative% Passing**	**63**	**40**	**20**	**16**	**12.5**	**10**
80mm	0	0	0	100	100		-	-	-	-
63mm	0	0	0	100	85-100	100	-	-	-	-
40mm	0	0	0	100	0-30	85-100	100	-	-	-

20mm	1949.50	1949.50	5.57	94.43	0-5	0-20	85-100	100	-	-
16mm	22970	24920	71.2	28.8	-	-	-	85-100	100	-
12.5mm	5705	30625	87.5	12.5	-	-	-	-	85-100	100
10mm	3731	34356	98.16	1.84	0-5	0-5	0-20	0-30	0-45	85-100
4.75mm	644	35000	100	0	-	-	0-5	0-5	0-10	0-20
Total (35000)										

Table 2.2 Sieve Analysis of Fine Aggregates

Fine Aggregate					**Specification As per IS-383**			
Total weight in gms= 1000					**Percentage Passing For**			
IS Sieve	**Weight retained (gm)**	**Cumulative weight retained (gm)**	**Cumulative % Retained**	**Cumulative% Passing**	**Zone- I**	**Zone-II**	**Zone-III**	**Zone-IV**
10mm	0	0	0	100	100	100	100	100
4.75mm	14.2	14.2	1.42	98.58	90-100	90-100	90-100	95-100
2.36mm	57.4	71.6	7.16	92.84	60-95	75-100	85-100	95-100
1.18mm	109.4	181	1.81	98.19	30-70	55-90	75-100	90-100
600µ	90.8	271.8	2.71	97.29	15-34	35-59	60-79	80-100
300µ	175.6	447.4	44.7	55.3	20-5	30-8	12-40	15-50
150µ	452.8	900.2	90.2	9.8	0-10	0-10	0-10	0-15
Pan	99.7	1000	99.7	0				
Total	1000	F.M=2.47						

2.2.2 Ordinary Portland cement

Three grades of ordinary Portland cement are available in market viz 33, 43 & 53 Grades. In this Dissertation work 43 grade of cement from single source is used (Jaypee cement). In the manufacture of cement basic raw material is clinker which is made from lime stone. The properties of cement conforming to IS 8112-1989 [33] are tabulated below

Table 2.3 Physical and chemical Properties of Cement

Property	Average Value	Standard Value as per IS 8112-1989
Specific gravity	3.15	
Consistency	32%	
Initial setting time	62 min	>30min
Final setting time	260 min	<600min
Soundness	2 mm	<10mm
Fineness	5% retained	
Compressive Strength(N/mm^2)		
3-days	24	>23
7-days	35	>33
28-days	47	>43
Chemical Properties		
Calcium Oxide CaO		
Silicon dioxide SiO_2		
Aluminium Oxide Al_2O_3		
Ferric Oxide		
Specific Surface Area(m^2/kg)		

2.2.3 Ultra fine slag (Alccofine)

Ultra fine slag or Alccofine is more advanced form of GGBS in which slag is further ground to less than 20 micron[1,3,5]. As a result its specific surface area is increased dramatically to 3000-5000m^2/kg (Bet Analysis). Particle shape of ultrafine slag is spherical (Scanning electron microscope) which due to ball bearing effect gives increased workability at much reduced water content. Ultra fine slag is produced in India by a joint venture with Ambuja cement ltd and Alcon developers with a brand name Alccofine. One of the unique properties of alccofine is its optimized particle size distribution as it is manufactured with special equipments in a controlled manner. Alccofine are available in market as per different percentages of calcium silicate. Alccofine 1203 has low calcium silicate and alccofine 1101 has high calcium silicate. Alccofine 1203 is generally used as supplementary cementing material due to its fineness and particle size whereas alccofine 1101 is used for soil stabilization purposes as a grouting material

2.2.4 Water

One cannot think concrete without water. Water used can be either for mixing different ingredients or for curing. When water is added then hydration reaction starts which forms strength giving C-S-H gel. It is well assumed that if water is suitable for drinking than it is suitable for making concrete. Water suitable for making concrete is also determined from its

Table 2.4 Physical and chemical properties of alccofine

Fineness	Specific gravity	Bulk density	Particle size		
			D_{10}	D_{50}	D_{90}
>12000cm^2/kg	2.9	700-900kg/m^3	1.5µ	5µ	9µ
Chemical Properties					
CaO	SO_3	SiO_2	Al_2O_3	Fe_2O_3	MgO
61-64%	2-2.4%	21-23%	5-5.6%	3.8-4.4%	0.8-1.4%

pH value. If pH value lies between 6 to 8 and free from organic compounds than it is suitable for making concrete. Strength of concrete also depends on water-cement ratio. More water no doubt contributing to workability of concrete but reduces its strength to some extent. Amount for water needed to achieve desired workability is usually more than that needed for complete hydration of the cement. Water used in this study was portable having following properties as tabulated in Table 2.5

Table 2.5 Physical and Chemical properties of water

Parameters	IS Standards	Results obtained	Maximum permissible limits as per IS 456: 2000
Organic	IS 3025 Part 18		200mg/l
Inorganic	IS 3025 Part 18		3000mg/l
Sulphates	IS 3025 Part 24		400mg/l
Chlorides	IS 3025 Part 32		2000mg/l for PCC and 500mg/l for RCC
Suspended solids	IS 3025 Part 17		
pH		6.8	Shall not be less than 6

2.3 Mix Design

For HPC there is no specific method of design mix. Based on the recommendations of IS 10262:1982 [30] the mix proportions of M60 Grade concrete was designed. Table 2.6 shows the quantities of different materials to be used for M60 concrete. The concrete was cast in cubical moulds of size 150mm×150mm×150mm and cylindrical moulds of size 100mm×200mm as conforming to IS 5816: 1999 [28]. As per IS 10086: 1982 [32] concrete beams were cast in mould size 500mm×100mm×100mm. All tests were performed in moderate exposure conditions. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. A careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. The concrete mixture was prepared by the concrete mixer. It was cleaned first by water and dried then, to ensure any impurities were not

adhering to its surface form prior use. OPC having 43 grades was used in casting. Dry fine aggregates are introduced first in the mixer & are thoroughly mixed. After that coarse aggregates are added to it. Then water was added carefully so that no water was lost during mixing. All the specimens were left in the steel mould for the first 24 hours at ambient condition. After that they were demoulded with care upon requirement of aging so that no edges were broken and were placed in the curing tank at the room temperature for curing. The room temperature for curing was 27ºC± 20ºC as per IS: 10262-1982 [30].

Table 2.6 Mix proportion for Grade M60

Grade	Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
M60	418	125.4	644	1127

2.4 Tests Conducted

2.4.1 Compressive strength

Concrete was prepared under moderate exposure condition and quality control was good. It was poured into cubical moulds and placed on vibrating table to minimize air entrapped which would otherwise affect the compressive strength. After 24 hrs the moulds were removed and the specimens were kept for curing at room temperature until taken out for testing. Specimens were tested at different ages i.e. 3 days, 7 days and 28 days compressive strength. The load is applied at a constant rate thus ensuring progressive increase in stress as failure approached. Table 2.7 shows different nomenclature used for different specimens. Cubical specimens with varying percentage of alccofine are designated by C0, C08, C10, C12, and C14.

Table 2.7 Compressive strength of concrete mixes, incorporating varying percentages of alccofine 1203 at 7, 14 and 28 days

Mix	Compressive strength in MPa			Average compressive strength in MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
C0	42.3	47.56	63.1	42.1	48	63.5
	41.7	48.23	62.5			
	42.3	48.23	62.5			
C8	42.89	61.45	69.10	43.32	62.6	71.2
	42.56	62.70	70.56			
	44.51	63.35	73.94			
C10	44.23	79.00	81.63	45.32	79.44	82.40
	46.50	78.25	82.10			
	45.16	81.07	83.40			
	44.57	82.21	89.20			

C12	46.56	83.92	88.43	47.32	83.13	88.60
	50.83	83.26	88.17			
C14	45.61	70.56	88.96	45.12	71.33	87.83
	45.36	71.89	88.08			
	44.39	71.54	86.45			

2.4.2 Flexural strength

Flexural strength is one of the important parameter of testing the strength of concrete.

For the determination of flexural strength beams of standard size 500mm×100mm×100mm as per IS 516:1959 was adopted.

Whole experiments were dived into two parts i.e. plain cement concrete beams and reinforced cement concrete beams. Total 45 nos of beams were casted for each grade and each type i.e plain cement concrete beams and reinforced cement concrete beam to be tested at different ages of curing. .

Reinforcement used was 2 bars of 8 mm dia as main reinforcement and vertical stirrups using 6mm dia @150mm c/c was used. Different nomenclatures used for plane concrete beams and reinforced concrete beams are tabulated in Table 2.8.

Beams were cured for 7, 14& 28 days time age. The beams were placed normal to the casting and symmetrical two point system was adopted for the flexural tensile strength test. The deflection of the beams was measured by the dial gauge of least count of 0.01mm, which was placed in the middle third portion of the beam.

Average flexural strength in plain and reinforced concrete showed an improved flexural strength up to 12% replacement.

Table 2.8 Nomenclature for specimens of beams used

Plain concrete beams	Reinforced concrete beams
C0	R0
C8	R8
C10	R10
C12	R12
C14	R14

Table 2.9 Flexural strength of plain concrete beams with varying percentages of alccofine at different ages of curing

Mix	Flexural strength in MPa			Average Flexutral strength in MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
C0	1.32	3.01	5.79	1.27	2.69	5.59
	1.22	2.09	5.32			
	1.28	2.98	5.66			
C8	1.51	3.10	6.23	1.34	2.93	6.26
	1.45	2.75	6.43			
	1.06	2.94	6.12			
C10	1.59	3.48	6.50	1.45	3.25	7.14
	1.23	2.97	7.40			
	1.53	3.30	7.52			
C12	1.70	3.80	8.56	1.58	3.58	8.14
	1.13	3.23	8.14			
	1.91	3.71	7.72			
C14	1.53	3.65	8.23	1.55	3.51	7.92
	1.48	3.35	8.01			
	1.64	3.53	7.52			

Table 2.10 Flexural strength of reinforced concrete beams with varying percentages of alccofine at different ages of curing

Mix	Flexural strength in MPa			Average flexural strength in MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
R0	3.15	8.57	18.14	3.02	8.34	18.05
	2.89	8.42	17.92			
	3.02	8.03	18.09			
R 8	3.44	8.65	18.01	3.21	8.99	20.49
	3.45	9.05	21.35			
	2.74	9.27	22.11			
R10	3.78	11.12	25.65	3.55	10.10	23.95
	3.15	8.89	21.12			
	3.72	10.29	25.08			
R12	4.89	12.75	28.36	4.06	11.84	29.34
	3.15	11.06	30.15			
	4.14	11.71	29.51			
R14	4.44	11.75	28.30	3.99	11.68	28.98
	4.06	10.73	30.15			
	3.47	12.56	28.49			

Table 2.11 Load vs deflection for concrete beams

Deflection (mm)	Plain concrete beam		Reinforced concrete beams	
	C0	C12	R0	R12
0.1	13.1	15.8	12.2	14.3
0.2	13.3	18.9	13.8	14.2
0.3	14.4	19.3	14.8	14.5

0.4	14.8	21.7	15.7	16.9
0.5	15.3	22.5	15.9	21.7
0.6	16.8	23.8	16.6	23.1
0.7	17.6	24.2	16.6	23.6
0.8	18.9	24.5	17.2	24.1
0.9	19.5	24.9	18.2	24.2
1.0	20.5	26.9	19.0	25.3
1.1	21.6	29.2	20.1	28.0
1.2	22.2	30.4	22.3	30.3
1.3	22.9	31	24.0	32.8
1.4	23.1	31	27.6	35.2
1.5	23.3	31	28.4	37.2
1.6	24.5	31	29.9	39.0

Fig. 2.1. Failure of reinforced concrete beams

2.4.3 Steel fiber reinforced concrete.

For the determination of split tensile strength varying percentages of steel fibers used were added in normal concrete along with ultrafine slag.

Amount of ultrafine slag was made fixed equals to maximum value that what was obtained in flexural strength. For split tensile test concrete cylinders and concrete beams with varying percentage of steel fibers and 12% alccofine were casted and tested at different ages of curing. Steel fibers have very marginal impact on flexural strength of concrete so they cannot replace entirely the traditional structural steel [24,23,21,26]. Amount of fibers used in concrete is expressed in terms of volume fraction (V_f) [9,13,15,16,17] which is defined as the amount of fibers added to the total volume of concrete mix. V_f generally ranges from 0.1% to 2% [16,21,22]. Most important parameter that plays an important role is the aspect ratio which is defined as the ratio of length to its diameter. Table 2.12 shows nomenclature used for different specimens. Cylindrical specimens with varying percentage of steel fibers are

designated by SC0, SC5, SC1, SC15 and SC20 and beam specimens are designated as CB0, CB5, CB1, CB15 and CB20.

2.4.4 Fire resistant test

The 100mm x 100mm x 100mm all with optimum percentage of (12 %) Alccofine -1203 were casted, moulded then prepared cubes were removed from the mould. At a time 36 cubes i.e. 3 sets of 12 cubes each were prepared out of which the first set was submerged for 7 days & other two sets for 7 and 28 days. Later those cubes were heated in the electric muffle

Table 2.12 Properties of steel fibers used

Length	**50mm**
Diameter	1mm
Appearance	Clear and Bright
Tensile strength	800-2500 MPa
Shape	Rectangular
Size	0.8mmx0.35mm
Aspect ratio	43.75

Table 2.13 Different nomenclature of specimen used.

Cylinder designation	Beam designation	% of alccofine (by weight)	% of steel fibers (by volume)
SC0	CB0	12%	0%
SC5	CB5	12%	0.5%
SC1	CB1	12%	1.0%
SC15	CB15	12%	1.5%
SC20	CB20	12%	2.0%

Fig. 2.2 Concrete cylinders with varying % of steel fibers

Fig. 2.3 Concrete beams with varying % of steel fibers

Table 2.14 Split tensile test on concrete cylinders at different ages with different % of steel fibers

Mix	Tensile strength MPa			Average Tensile strength MPa		
	7 days	14 days	28 days	7 days	14 days	28 days
SC0	1.2	3.4	5.9	1.2	3.5	5.9
	1.1	3.6	6.1			
	1.4	3.6	5.7			
SC5	1.2	3.5	6.1	1.2	3.6	6.1
	1.2	3.6	6.1			
	1.3	3.6	6.0			
SC10	1.3	3.9	6.7	1.3	3.9	6.7
	1.3	4.0	6.6			
	1.3	3.9	6.9			
SC15	2.6	4.5	7.9	2.4	4.4	8.2
	2.3	4.3	8.2			
	2.2	4.4	8.4			
SC20	2.3	3.9	7.5	2.2	3.8	7.6
	2.3	3.5	7.5			
	2.0	4.0	7.8			

furnace. In order to maintain different ranges of constant temperature a thermostat is used in the muffle furnace [19,14]. These sets were heated for 1, 2, 3 hours duration at 4 different temperatures (27ºC, 500ºC, 650ºC, 800ºC). After that these sets were left at room temperature for 24 hours for cooling. Compressive strength has been calculated as per BIS 516-1959. Each of the samples selected for testing has been be exposed to the desired duration once it as reached the desired temperature. After fire resistance test, compressive strength of the samples was determined to detect effect of fire on strength properties of concrete cubes. Concrete on heating it expands & contracts on cooling. Restraint to contraction causes the development of tensile stresses. The temperature related contraction stress can cause cracking. Cracks may also be caused by differential temperatures in thick members. When the surface layer cools and contracts, movement is restrained by the core of the member which is still at a higher temperature, and hence cracks may form in the surface.

Table 2.15 Flexural strength of Steel fiber reinforced concrete beams

Mix	Flexural strength MPa			Average flexural strength MPa		
	7 days	14 days	28 days	7 days	14 days	28 days
SB0	1.38	3.23	8.10	1.39	3.29	8.06
	1.45	3.36	7.88			
	1.34	3.30	8.20			
SB5	1.42	3.48	8.48	1.40	3.40	8.43
	1.39	3.33	8.39			
	1.40	3.39	8.42			
SB10	1.47	3.44	8.77	1.44	3.44	8.73
	1.44	3.43	8.72			
	1.41	3.44	8.71			
SB15	1.66	3.88	10.43	1.63	3.81	10.45
	1.64	3.78	10.48			
	1.60	3.77	10.44			
SB20	1.62	3.57	8.57	1.55	3.52	8.50
	1.49	3.52	8.43			
	1.55	3.48	8.49			

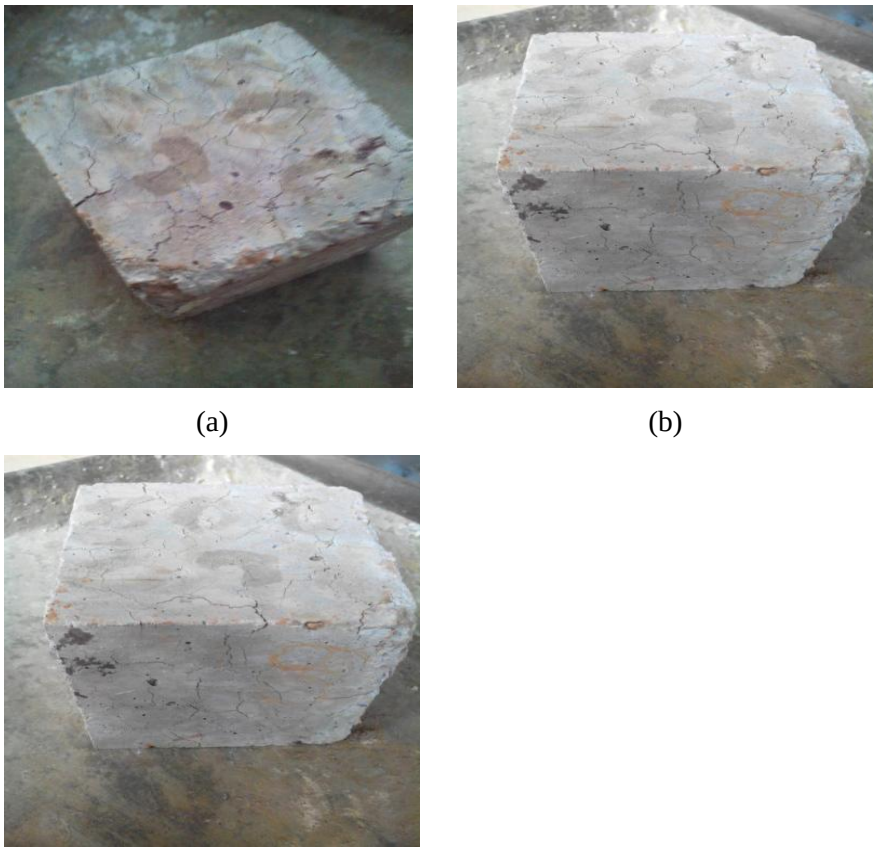
Inferences based upon appearance:

i) At 500ºC: Cubes experience minor cracks and dehydration of the cementitious paste with complete loss of free moisture and a reduction in paste volume.

ii) At 650ºC: Prominent cracking of both the cementitious paste & aggregates due to expansion. Color of concrete turns somewhat pinkish.

iii) At 800ºC: Complete dehydration of the cementitious paste with considerable shrinkage cracking, was observed. Concrete becomes crispy and easily broken down upon contact. Colour of concrete changes to grey.

The temperature range and exposure duration controls the strength of concrete at an elevated temperature. The test results are presented in Table 2.16. Fig 2.4 shows the effect of elevated temperature of concrete cubes. Superficial cracks are generated to cube surface due to thermal gradient. From Table 2.16 it can be observed that initially there is increase in percentage residual compressive strength when cubes are heated at 500ºC but there after its strength decreases.



(a) (b)

(c)

Fig. 2.4 Superficial cracks on cubes due to varying thermal gradient

Table 2.16 Compressive and % Residual compressive strengths of cubes after exposing to elevated temperature cured for 28 days.

Temperature		Compressive strength in MPa			% Residual compressive strength in Mpa		
		1 hour	2 hour	3 hour	1 hour	2 hour	3 hour
27^0 C	C0	63.5	63.5	63.5	100	100	100
	C12	88.6	88.6	88.6	100	100	100
500^0 C	C0	73.66	62.61	45.06	116.1	98.61	70.97
	C12	105.25	89.3	75.6	118.8	99.2	85.3
650^0 C	C0	68.91	60.71	33.40	108.53	95.61	52.59
800^0 C	C0	34.81	33.77	31.21	45.17	46.82	49.14

2.4.5 Durability analysis

In order to conduct the durability analysis first of all different materials i.e cement, sand coarse aggregates were weighed properly and dry mixing was done. Water was added after proper dry mixing and quantity of water was taken as per proposed mix design. After proper mixing of all the ingredients the fresh concrete was poured in cubical moulds of size 100 mm x 100 mm x 100 mm and proper compaction was done by placing the moulds filled with fresh concrete in a compaction table.

Fig. 2.5 Cubes immersed in respective solutions

Table 2.17 Compressive strength reduction of referral concrete after curing in water

Designation	% of Alccofine	Compressive Strength after curing in 100% water (MPa)	Compressive Strength after curing in 5% HCL (MPa)	Compressive Strength after curing in 5 % H_2SO_4 (MPa)	% Reduction in compressive strength	
					5%HCL	5% H_2SO_4
AC_0	0	63.5	61.5	59.02	3.14	7.05
AC_6	6	69.25	68.84	64.23	0.58	7.25
AC_8	8	71.20	78.96	60.18	0.57	15.48
AC_{10}	10	82.40	81.94	58.65	0.55	26.13
AC_{12}	12	88.60	88.14	57.27	0.52	35.63
AC_{14}	14	87.83	87.56	55.89	0.30	36.36

In this study five different mixes of M60 grade of concrete were prepared as shown in the Table 2.17. AC_0 refers to the concrete cubes containing 0% alccofine and AC_{12} represents concrete with 12% alccofine as replacement of cement. After 24hrs, the cubes were demoulded and then kept in respective three different solutions for curing. Three different solutions used for curing were 5% HCL, 5% H_2SO_4 and water. The cubes are taken out for testing after from 30 days of curing at respective solutions. Concentration of solutions was maintained throughout this period in interval of 15 days. After 30 days the specimens were taken out from respective solution. The surface of specimen was cleaned and weights were measured. The mass loss and strength of specimen due to acid attack was determined and has been presented in Table 2.17.

3. RESULTS AND DISCUSSIONS

3.1 General

In this chapter the results of all the tests that were conducted in accordance with chapter 2 are discussed. Compressive strength, Flexural Strength, Tensile strength and Sulphate resistance & Chloride resistance of various concrete mixes incorporating ultrafine slag (Alccofine-1203) in varying percentages is discussed.

3.2 Compressive Strength

The test results indicated that, when 8% to 12% by weight replacement of alccofine 1203 for cement is done, compressive strength increases. When 14% replacement of cement is done strength starts decreasing. Compressive strength of ultrafine slag concrete at 28days when compared to control mix was found to increased by 11% to 39 % on increasing the alccofine content from 8% to 12%. Also there is 10% to 37% increase in 28 days strength with 14 % replacement when compared to control specimen. Decrease of compressive strength is noticed when compared to 12% replacement level. The results here establish that the optimum value for replacement of cement by alccofine 1203 is 12%

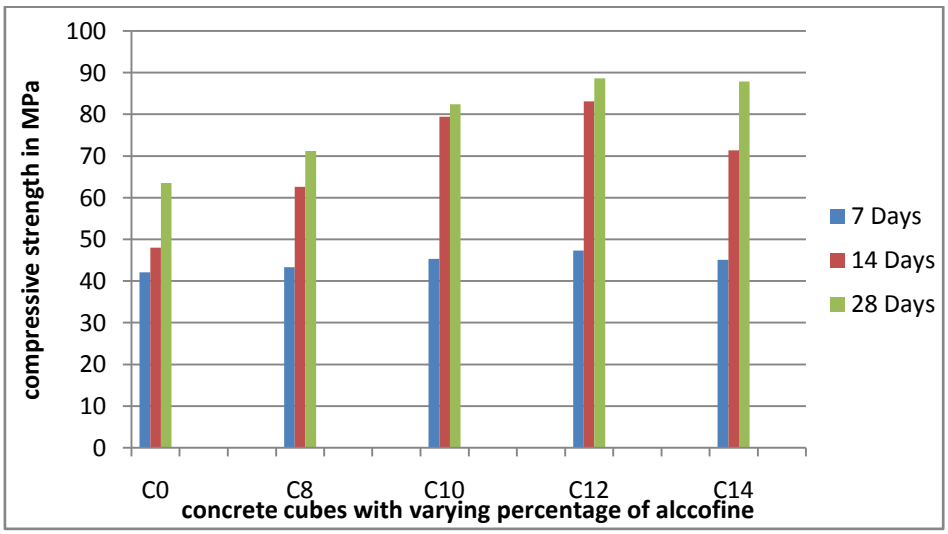


Fig 3.1 Comparison of compressive strength of concrete cubes at ages of 7, 14and 28 days of curing

3.3 Flexural Strength

From the results listed in Table 2.9 and Table 2.10 it is obtained that in both cases of plain and reinforced concrete beams the 28 days strength of all the mixes is invariably higher than corresponding 7 days and 14 days strength. This is due to continuous hydration of cement with concrete and improved particle packing owing to the dimensions of alccofine particles. However a fall in strength was seen when replacement level exceeded 12 %.

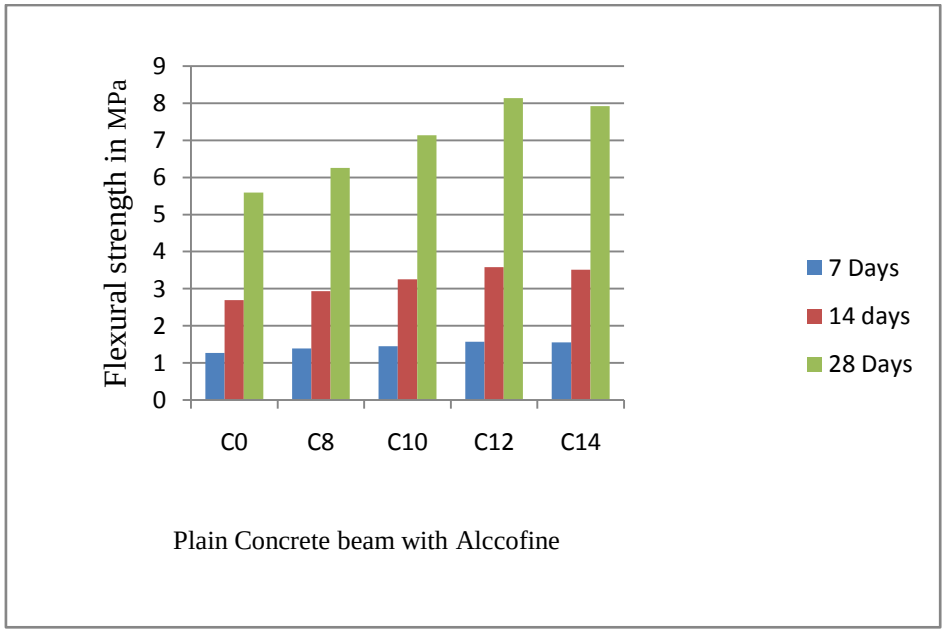


Fig 3.2 Variation of Flexural strength of plain concrete beams with different % of alccofine

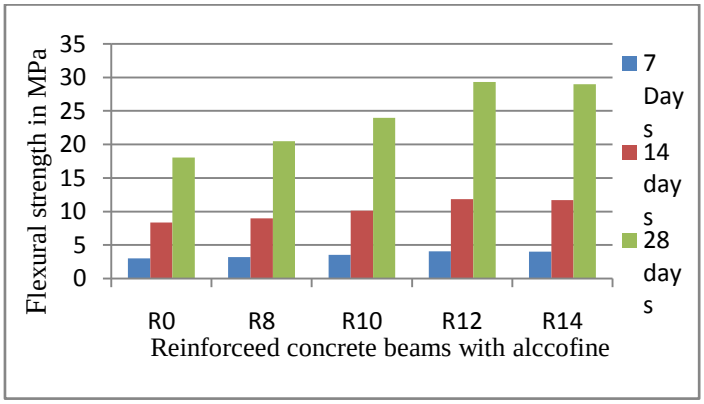


Fig 3.3 Variation of Flexural strength of plain concrete beams with different % of alccofine

3.4 Split Tensile Test and flexural strength of SFRC

As compared to the referral SFRC, the split tensile strength is maximum at steel fiber with 1.5% (SB 15) addition by volume. Replacement of 12% Alccofine is common to all mixes

and it is nearly 43.7%, 39.43% and 31.29% more than that of referral SFRC at 7, 14 and 28 days respectively. Split tensile strength of referral concrete as well as SFRC at 7, 14 and 28 days are given in Table 2.14 and Table 2.15 and the variation of split tensile strength of specimens at different replacement level of steel fibers is shown in Fig. 3.4 and Fig. 3.5

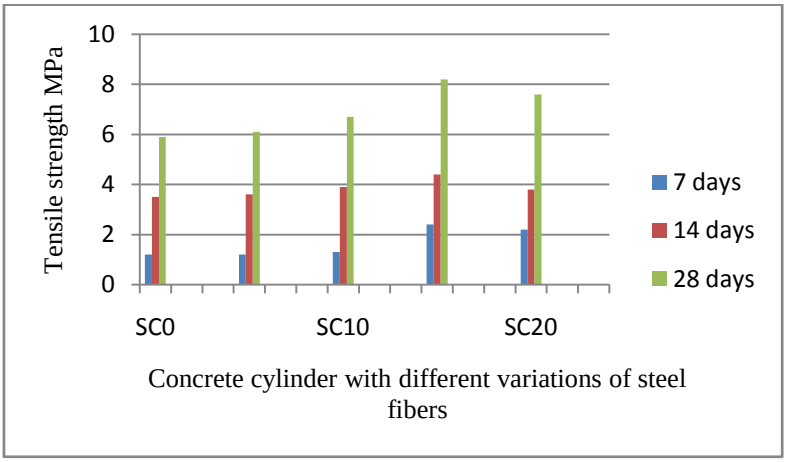


Fig. 3.4 Comparison of tensile strength of concrete cylinders with different variations of steel fibers**.**

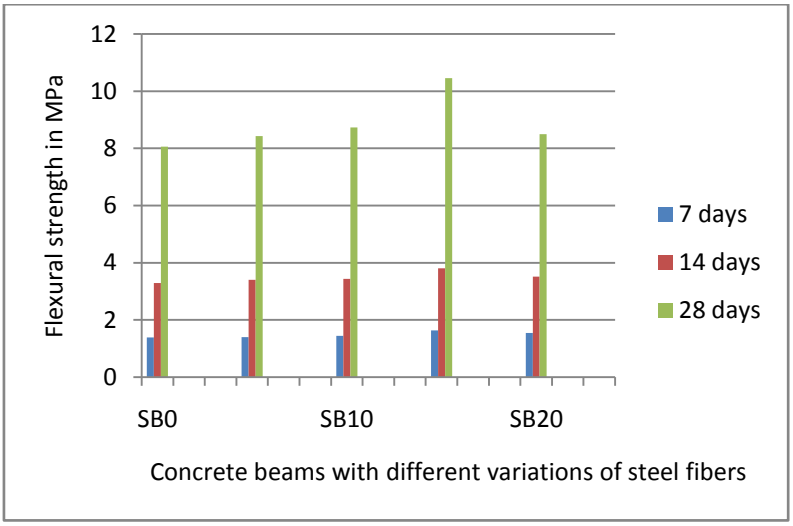
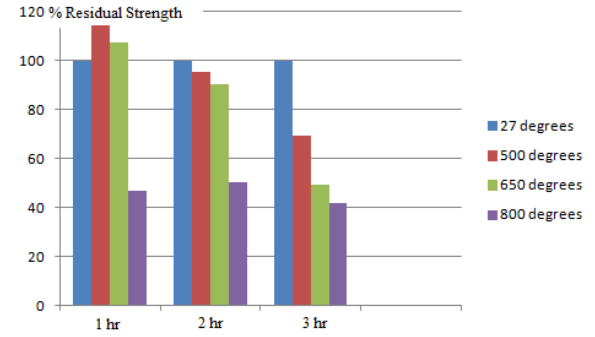


Fig. 3.5 Comparison of flexural strength of concrete beams with different variations of steel fibers.

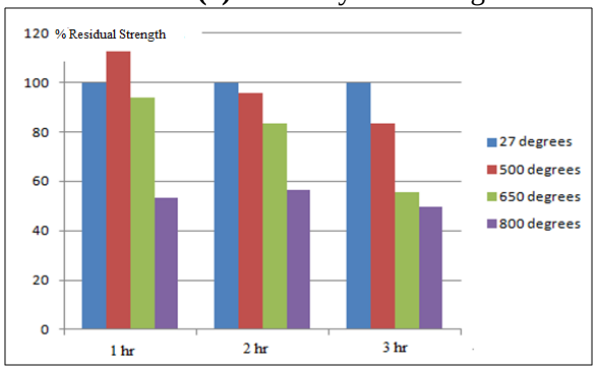
3.5 Fire Resistant Test

The variation of Compressive strength with the increase in temperature is studied in terms of the percentage residual compressive strength for different durations of 1, 2 & 3 hours. Initially, the strength increased with temperature 27ºC to 500ºC for different durations and beyond that it was reduced. The maximum Compressive strength was noticed when the cube

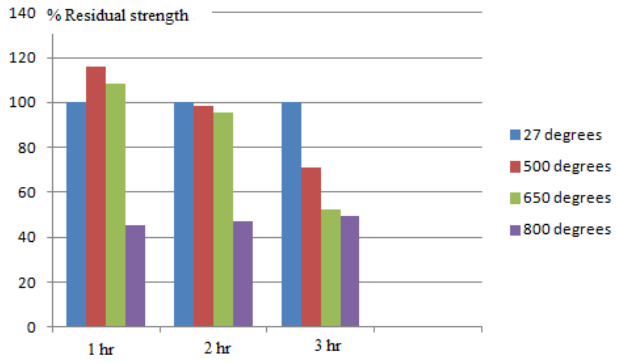
was heated at 500ºC for 1 hour duration. The compressive strengths are increased up to 27ºC -500ºC & beyond that it was rapidly reduced with increasing temperature. The compressive strength was lost very much when they are heated to temperatures greater than 800ºC.



(a) At 7 Days of Curing



(b) At 14 Days of Curing



(c) At 28 Days of Curing

Fig. 3.6 Variation of % Residual compressive strength with temperature at different ages of curing.

3.6 Durability Analysis Test

The conversion of calcium compounds into calcium salts of the attacking acid. These reactions destroy the concrete structure. There is reduction in loss of compressive strength of concrete after curing in 5% HCL when compared controlled concrete. Thus replacement of alccofine is found to have increased the durability against hydrochloric acid attack. This is due to the silica present in alccofine which combines with calcium hydroxide and reduces the

amount susceptible to acid attack. Sulphate attack denote an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. Alccofine concrete suffers a rapid loss of compressive strength as soon as it is exposed to sulphuric acid.

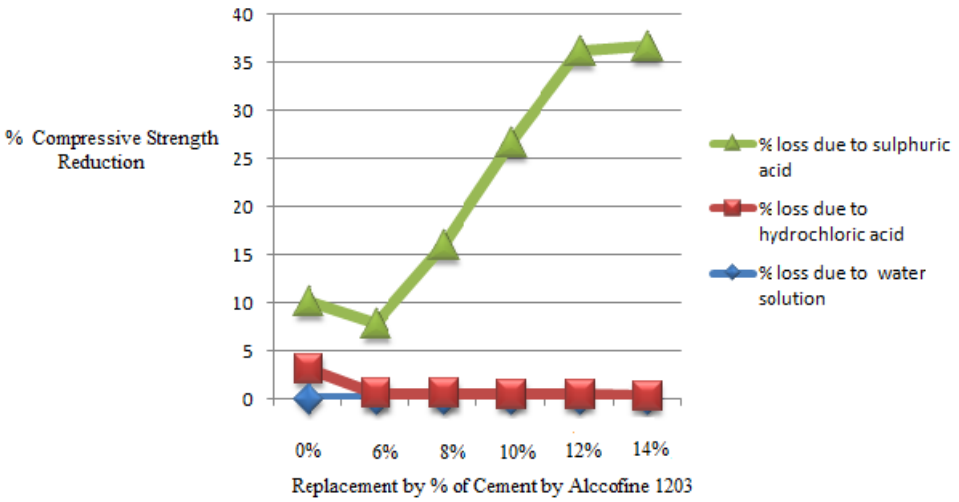


Fig 3.7 Reduction in compressive strength of concrete cubes cured under different solutions

4. CONCLUSIONS

Detailed laboratory experiments performed on M60 grade of concrete with water cement ratio 0.3 is discussed in preceding Chapters. Main aim of this study is find the optimum dose of alccofine that can be preplaced by cement and how this material affects the strength and durability of concrete. The major experimental outcomes are as follows

- Compressive strength of concrete increases after adding alccofine. Optimum dose of alccofine that can be replaced is 12%. As compared with controlled concrete there is 39.5% increase in compressive strength.
- Flexural strength of plain concrete beams at 12% replacement of cement with alccofine shows 45% increase in flexural strength when compared with controlled concrete.
- Flexural strength of reinforced concrete beams at 12% replacement of cement with alccofine shows 62% increase in flexural strength when compared with controlled concrete. From Table 2.11 it can be concluded that to achieve same amount of deflection higher amount of load is required in case of concrete incorporated with alccofine.
- There is significant increase in split tensile strength of steel fiber reinforced concrete when compared with controlled concrete. There is increase in 38% of split tensile strength of concrete cylinders with 12% alccofine and 1.5% by volume of steel fibers. There is also significant increase in flexural strength of steel fiber reinforced concrete beams with same amount of alccofine and steel fibers.
- Fire resistant test was also conducted to find the residual compressive strength after increasing the temperature of concrete upto 800ºC. It has been observed that along with increased compressive and flexural strength of concrete, it can also withstand the elevated temperature upto a certain value. As seen from Fig.3.6 at 28 days of curing maximum % residual compressive strength was noticed when the cubes were heated at 500ºC for 1 hour.
- From durability analysis test it can be concluded that the concrete incorporating ultra fine slag(alccofine) shows much improved resistant to acid attack. From Table 2.16 it can be observed that % reduction in compressive strength of concrete cubes incorporating alccofine cured in 5% HCL is much less than ordinary concrete cured under same conditions.

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6. LIST OF PUBLICATIONS

6.1 Journal Publications

[1] Saurav, Gupta, A.K. (2017). "Experimental investigation to find the optimum dose of steel fibers in concrete incorporating ultrafine slag". *Journal of Engineering science and Technology*. (**Accepted**). [**Scopus Indexed**]

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